THE LAND SURFACE COMPONENT OF THE NORTH AMERICAN CARBON BUDGET

Testimony before the Committee on Government Reform
Subcommittee on Energy and Resources
Darrell Issa, Chairman
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I. Introduction

Science and policy questions for the carbon budget of North America

Reliable, specific knowledge of the sources and sinks of CO_2 in nations of North America is needed in order to formulate policy options for managing US emissions of CO_2 to the atmosphere. We consider here the scientific questions that must be addressed in order to provide the needed information to society and to decision makers.

Human-caused emissions of CO_2 are due primarily to combustion of fossil fuels, with small contributions from cement manufacturing and land use change.

- What are the current sources, past trends, and future projections for human-caused emission of CO_2 to the atmosphere?
- What are the underlying factors that regulate the past, present, and future emissions?

These questions are addressed in the testimony of Dr. Gregg Marland.

Managed and unmanaged ecosystems currently constitute a land sink for atmospheric CO_2 in North America.

- What is the magnitude of the current uptake of CO_2 from the atmosphere due to biological processes, past trends in this quantity, and projections of the future?
- What are the underlying factors that regulate the past, present, and future magnitude of this uptake?
- Can the "land sink" be managed to help offset fossil fuel emissions?
- What are the major uncertainties that need to be addressed by scientific research in order to provide society and decision makers with the best possible information about sources and sinks of CO_2 in North America?

These questions are addressed here, in response to the request of the Subcommittee for "testimony [that] detail[s] information regarding what is and is not known about carbon sinks in the United States and the exchange of carbon between the atmosphere and natural systems."

The State of the Carbon Cycle Report (SOCCR, 2006)

This testimony relies on a comprehensive assessment of the carbon budget for North America, the State of the Carbon Cycle Report [Dilling et al., editors], cited in this document as "SOCCR, 2006". SOCCR (2006) is element 2.2 of the Synthesis and Assessment Products of the U. S. Climate Change Science Program (CCSP), intended "to provide the best possible scientific information to support public discussion, as well as government and private sector decision-making, on key climate-related issues." It has been developed over a two-year period by dozens of scientists. It has received a first round of scrutiny and public review, and is currently undergoing the final stages of review. SOCCR (2006) is an authoritative reference to address questions of past, present, and future uptake of atmospheric CO_2 by land ecosystems in North America.

Currently, "bottom up" scientific studies (e.g. Houghton et al., 1999; Pacala et al., 2001) provide the principal sources of information for assessing the magnitude of sources and sinks of CO_2 in North America. These studies use inventories of timber stocks in forests (in the U.S., the USFS Forest Inventory Analysis) and soil organic matter in agricultural lands (in the U.S., the USDA National Resources Inventory), plus remote sensing, to construct a sophisticated spreadsheet detailing the total amount of carbon stored as organic matter across the continent. By examining the changes in these totals over time, a carbon budget has been constructed in SOCCR (2006).

Bottom-up carbon budgets require considerable extrapolation from the actual measurements. Lands in many cover classes are not inventoried, in particular, Western lands subject to woody encroachment are mostly not surveyed. In Canada and Mexico, national scale data are not available. Carbon budget analysis requires subtracting values for two inventories, and thus reliable values cannot be obtained for intervals shorter than 5-10 years. This requirement limits how much can be learned about *why* observed changes have occurred. Inventories are conducted to manage economically valuable resources, not for carbon accounting, and thus important pools of organic matter are omitted.

SOCCR (2006) points out that carbon budgets at sites in the DoE AmeriFlux network have converged with inventory budgets. The AmeriFlux "eddy covariance" towers make direct measurements at ~1 hr time resolution of fluxes from the whole ecosystem. Data for some of AmeriFlux sites extend to 10 years or more, and agreement with inventory data at these locations lends confidence to the inventory-based budgets. So far, however, this comparison can be carried out at just a handful of sites.

The North American Carbon Program (NACP; Wofsy and Harriss, 2002; Denning et al., 2005) is intended to develop and test an observing system capable of using measurements of atmospheric CO_2, combined with remote sensing and meteorological data, to provide a "top down" budget. Figure 1 displays a key element of the NACP strategy, a tall tower observation station (NOAA-ESRL) that continuously measures the concentrations of CO_2 and other gases several hundred meters above the ground. These data provide a measure of the net flux of CO_2 from the surface over a large area of North America, extending for several hundred miles. Many of these towers are needed to construct a reliable carbon budget for North America, and it remains scientifically challenging to validate the uptake rates derived from the data.

Other elements of the NACP include remote sensing data for vegetation state and CO_2 concentrations (NASA), enhancement of the inventory programs (DoA), the network of flux towers noted above (DoE), and intensive studies to validate methods (NSF). NOAA has prepared the equipment to set up a large number of tall-tower stations. The current phase of the NACP focuses on testing the concepts for the top-down determination of the North American carbon budget. Note that, since air does not recognize national borders, the top-down analysis necessarily treats the budgets of Mexico and Canada as well as in the US.

II. Summary of what we know

What are the magnitudes of the current uptake of CO_2 from the atmosphere due to biological processes, past trends in the carbon budget, and projections of the future?

SOCCR (2006) provided a summary of what we know about the contribution of vegetation and soils to the carbon budget for North America:

- During the 18th, 19th, and the first part of the 20th century, the plants and soils of the United States and Canada were sources for atmospheric CO_2 due to expansion of croplands into forests and grasslands. In recent decades these regions shifted from source to sink as forests returned to many areas, and as western woodlands and forests accumulated fuel due to fire suppression and reduced logging. In Mexico, emissions of carbon continue to increase from net deforestation.
- The future of the North American land carbon sink is highly uncertain. Uptake by recovering forests may decline as the forests mature, but we do not know how quickly this may occur. Moreover, some current uptake may be stimulated by deposition of nitrogen from air pollution and by rising CO_2 concentrations in the atmosphere. We do not understand the magnitude of these "fertilizing" effects, nor can we quantitatively assess the impacts of ozone pollution or climate change.
- There appear to be good options for mitigating (10-30%) fossil fuel emissions by managing North American forests, rangelands, and croplands to increase carbon storage, but current uncertainties are large. Ideas for managing ecosystem carbon budgets are most competitive when other goals are served at the same time, for example, conservation of soil and water resources, or production of food or fiber.
- There is a risk that carbon sequestered in land ecosystems may be released by natural phenomena or human activities.

Table 1 summarize these conclusions quantitatively, showing that the land sink currently removes from the atmosphere just over ¼ of the fossil fuel emissions from North America. Figure 2 disaggregates the land sink into sectors, including forest growth, woody encroachment due to fire suppression in semi-arid areas, wood products, accumulation in wetlands (natural zones for deposition), and trapping of eroded sediment in rivers, reservoirs, and estuaries.

What are the underlying factors regulating the past, present, and future magnitude of the "land sink"? Can management of ecosystems help offset fossil fuel emissions?

Forest growth and wood products are, together, by far the largest and best-studied components of the land sink, with comprehensive data from forest inventories. Most current forest growth is a legacy of prior land use, especially reforestation of the Northeast and Southeast in the 19th and 20th centuries as agriculture industrialized and moved elsewhere. There are subtleties in accounting for this uptake in a policy context, especially for any system of "carbon trading" that might be considered. Industrialized agriculture is energy intensive, and thus the forest carbon sink comes at the cost of energy use elsewhere. Nevertheless the sink is surprisingly large. It appears feasible, and likely economically profitable, to adopt management practices which sustain and enhance storage of carbon, particularly when combined with economic activities that produce renewable fuels, fiber, or food, or with efforts to protect water, air, or biological resources.

Data from several of the longer-running stations of the DoE AmeriFlux network have tended to indicate increasing rates of uptake of CO_2 from the atmosphere over the past 10—15 years, even in places like the 85-year–old Harvard Forest in Petersham, MA

(Figure 3; source: Urbanski et al., 2006) or the 160-year-old Thompson site in Manitoba (Dunn et al., 2006). The hourly data from the AmeriFlux "eddy covariance" towers provide a direct measure of the carbon flux from a whole forest ecosystem, including soil processes. Acceleration of uptake in these older sites is very surprising, and it appears to support the view that could be sustained and enhanced. The underlying causes are not known, however, and uptake data are available for just a few sites. Possibilities include favorable shifts in climate just at these sites, global-scale stimulation of plant growth by rising CO_2, and other factors. This is an area of active scientific research, although it requires long-term research that may be difficult to support on a sustained basis.

Woody encroachment in fire-prone areas of the West represents the second largest component of the land sink, and the most uncertain. These lands have low commercial value and most are not inventoried. Unlike the beneficial and valuable carbon stored in forests, the accumulation of fuel in these areas represents a problem, threatening more severe fires with the high risk of rapid return of sequestered carbon to the atmosphere. Likewise the trapping of sediment in reservoirs is problematic, resulting from soil loss and limiting the lifetime of water projects.

Carbon sequestration in agricultural soils results largely from shifts to minimum tillage or no tillage. The associated uptake is quite small, limited by the cropping regime and other factors. However, reduced tillage practices offer significant benefits in soil conservation, conditioning, and reduction of inputs. Carbon sequestration enhances those values for the farmer and for society.

Wetlands naturally trap organic matter, growing and shrinking over centuries and millennia. They contain vast stores of carbon, preserved by anaerobic conditions in waterlogged soils. The response to climate change of organic matter in wetlands is one of the major uncertainties for the future of the carbon budget, as noted below.

Projections into the future generally predict constant or declining uptake of CO_2 by the land sink, in North America and globally. A number of carbon—climate coupled models were run recently in preparation for the fourth report of the IPCC (Friedlingstein et al., 2006). The models generally agree in projections that show negative impacts of climate change on vegetation and soils at low latitudes, where temperatures are projected to rise and soils to become drier. Affected areas may include the Southeastern U.S. (e.g. Fung et al., 2005; Figure 4). However, there are major differences between the models for high latitudes, with some predicting net carbon gains and some losses. These discrepancies largely reflect differences in the model projections for soil moisture.

III. Summary of what we don't know, but would like to understand

What are the major uncertainties that need to be addressed by scientific research in U.S. in order to provide society and decision makers with the best possible information about sources and sinks of CO_2 in North America?

There are two scientific issues of the highest priority needed to provide key information to society and to policy makers:

(1) *We must develop the capability to make accurate, reliable measurements of the carbon emissions and uptake for North America, resolved by season and region.* This is the primary information needed to make informed judgments about non-fossil sources

and sinks for CO_2, to assess the efficacy of any strategies adopted to restrain CO_2 increase in the atmosphere, and to ascertain the effects of climatic anomalies and trends on the North American carbon budget.

Determination of the carbon budget on regional and continental scale requires strong research efforts to strengthen both bottom-up (inventory) and top-down (atmospheric) methods, and eventually to combine these into a “data fusion” approach. The strategy for this program is set forth in NACP planning documents (Denning et al., 2005; Wofsy and Harriss, 2002). Multi-agency coordination and innovative research programs are the foundation of the plan.

The core observational elements of the top-down method are the NOAA ESRL tall tower network and associated weekly aircraft ascents, remote sensing data for vegetation state and CO_2 total column (NASA), and improved high-resolution meteorological analysis products (NOAA). Significant developments of theory and of computer models are needed to use these data (supported by many agencies). Intensive validation studies using aircraft and ground observations (NASA, NSF) are essential for success of the program.

The main elements of the bottom-up method are the inventories (DoA), which need to be expanded to cover all major vegetation types and land uses and to account for all significant pools of organic matter, plus remote sensing (NASA). Hence we need substantial enhancement of the inventory programs. The AmeriFlux program (DoE) of ecosystem flux observations provides essential validation for this effort.

(2) *We need to understand the processes that regulate the carbon cycle on regional and continental scales in North America.* These insights are required to provide increased confidence in projections of future carbon budgets, and to devise management strategies that enhance carbon sequestration in North American ecosystems while simultaneously optimizing other economic and social values. The elements laid out in (1) provide the foundation for gaining mechanistic understanding. In addition, large—scale ecosystem manipulations (DoE, NSF, DoA) are essential to probe the response of ecosystems to future conditions of climate, atmospheric CO_2, nutrient deposition, air pollution, and management.

IV. References

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V. Tables and Figures

Table 1a. North American contribution to the global carbon budget of approximately the 1990s. Global values are from IPCC (2001). The North American terrestrial sink estimate is from SOCCR (2006). Values are in millions of tons of C per year, positive ⇒ emissions to the atmosphere, negative ⇒ uptake from the atmosphere.

Component	**Global budget[a] (Mt C yr^{-1})**	**North America[b] (Mt C yr^{-1})**	**North American fraction (%)**
Atmospheric increase	3200 ± 100	*not applicable*	*not applicable*
Human-caused emissions (fossil fuel, cement)	6300 ± 400	1640 ± 164[c]	26%
Ocean-atmosphere flux	–1700 ± 500	20 ± 20	1%
Emissions from land-use change	1600 ± 800[d]	–37[e]	2%
Terrestrial Sink	–2300 ± 1300	–600 ± 300[g]	26%

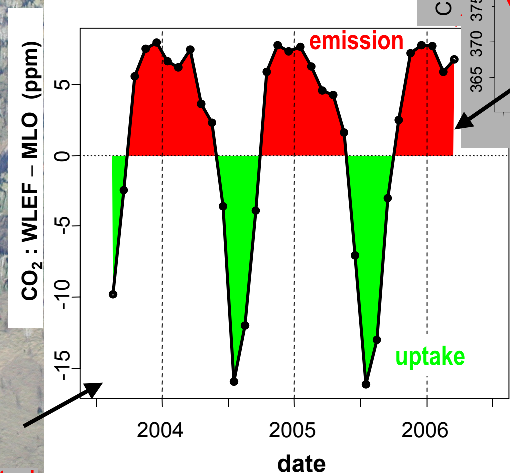
[a] Global uncertainties are ± 1 standard error (67% confidence intervals) (IPCC, 2001).
[b] North American uncertainties are 95% confidence intervals (see Chapter 3 SOCCR, 2006).
[c] Average emissions for 1990–1999 (Marland *et al*., 2006). [d] Estimate for 1989–1995 (IPCC, 2000).
[e] U. S. only, for the 1980s (Houghton *et al*., 1999).
[g] Estimated from changes in inventories of carbon stored in plants and soils.

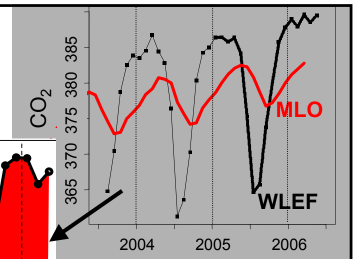
Table 1b. Nonfossil carbon sink, by country and sector. (Source: SOCCR, 2006)

Source (positive) or Sink (negative)	**United States**	**Canada**	**Mexico**	**North America**
Fossil source (positive)				
Fossil fuel (oil, gas, coal)	1582	164	110	1857
Nonfossil carbon sink (negative) or source (positive)				
Forest	–259	–99	+52	–306
Wood products	–57	–10	ND	–67
Woody encroachment	–120	ND	ND	–120
Agricultural soils	–4	–0	0	–4
Wetlands	–41	–25	–4	–70
Rivers and reservoirs	–25	ND	ND	–25
Total carbon source or sink	**–506**	**–134**	**48**	**–592**

Figure 1

Tall tower CO_2 stations

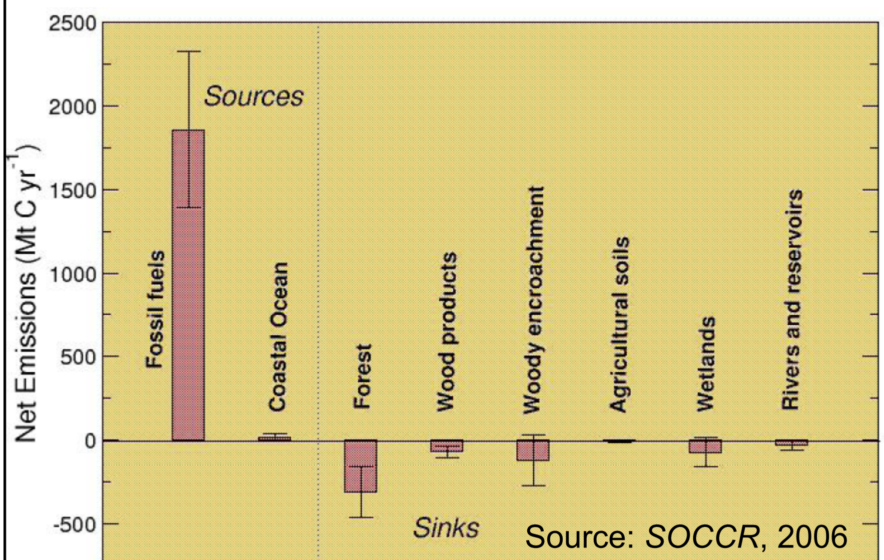




Source: NOAA-ESRL

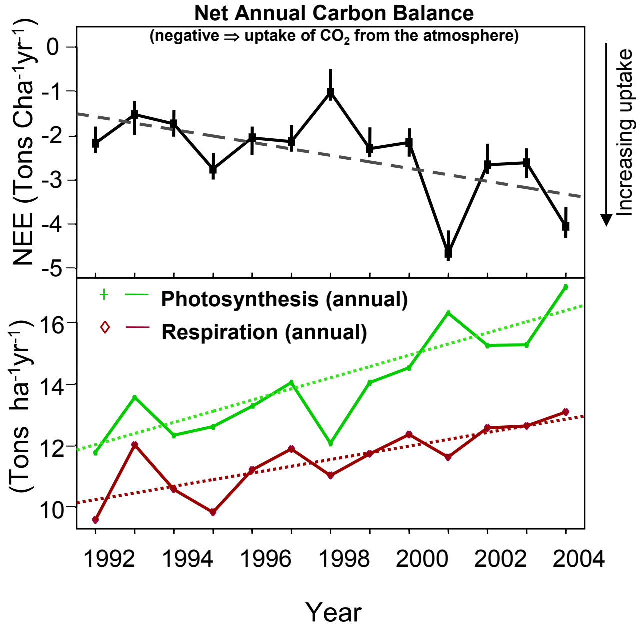
(*left*) WLEF tower with observation of CO_2 at six levels, the highest 396 m above ground level. (*upper*) Monthly mean concentrations at WLEF (396 m) and Mauna Loa (HA), which represents the hemispheric background. (*center*) The difference between WLEF and Mauna Loa. **The tall tower measures the emission or uptake of CO_2 from a large region of North America. A network of these tower stations is planned for the North American Carbon Program.**

Fig. 2. North American carbon sources and sinks (Mt C yr^{-1})



Height of a bar indicates a best estimate for net carbon exchange between the atmosphere and the indicated element of the North American carbon budget in 2003. Error bars indicate uncertainty in that estimate, and define the range of values that are believed to include the actual value with 95% certainty.

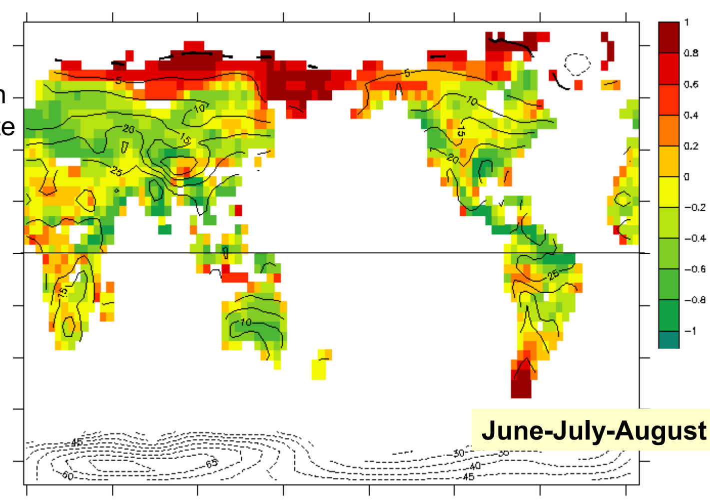
Figure 3. Carbon budgets of whole forests



Long-term carbon balance in a New England Forest. The DoE AmeriFlux Network uses advanced methods to directly measure the carbon balance ("NEE", Net Ecosystem Exchange) of forests every hour. Data for long-running stations using this "eddy covariance" technique have tended to indicate increasing rates of uptake of CO_2 from the atmosphere, even in places like the 85-year–old Harvard Forest in Petersham, MA (data shown at the left; source: Urbanski et al., 2006).

Figure 4. Temperature-Soil Moisture Correlation for Projected Climate in 2100.

Source: I. Fung, S. Doney, K. Lindsay, J. John, P. Friedlingstein, 2005. Colors show correlation coefficients for T and soil moisture between 2000 and 2100.

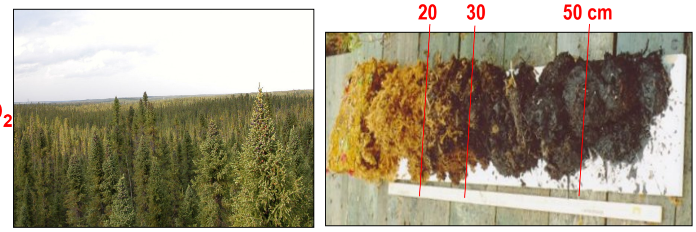


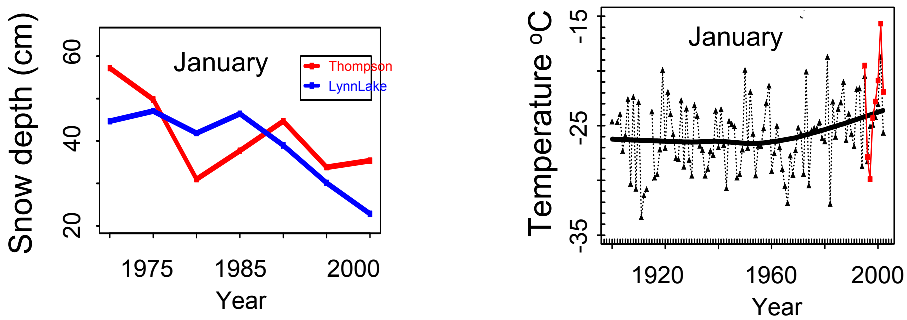
Projected changes in temperature and soil moisture in 2100. Areas shown in green (Southeastern US, Central America, Amazon Basin, most of Russia and South and West Asia) get warmer and drier, and are projected to experience more severe drought episodes and increased moisture stress on the vegetation. Significant release of CO_2 from would be expected from soils and vegetation in these areas. Areas in red get warmer and wetter, and might experience increased carbon sequestration.

Warmer and wetter

Warmer and drier

Figure 5. Will warming of North America release 100s of ppm of CO_2 from Alaskan and Canadian peat?





Forests and bogs in Canada, Alaska and Siberia contain vast stores of organic matter in peat-laden soils (*upper panels*), equivalent to 200—400 ppm of CO_2 if oxidized and released to the atmosphere. The peat accumulated over thousands of years, preserved by being waterlogged and/or frozen. Climate has warmed markedly in these regions since 1960, and snow cover has declined (*lower panels*). Accumulated peat could be oxidized quickly by microbial activity or by combustion, should it thaw and dry out. Some climate models predict vast releases of CO_2 by this process due to climate change in this century, but others project increased precipitation that preserves and enhances stores of peat. (Thompson, MB, photos and data; Source: Dunn et al., 2006)